Open Charm Physics at CLEO-c

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Recent CLEO-c results on open charm physics at the $\psi(3770)$ are presented. Measurements of hadronic and semileptonic branching fractions of the D^0 and D^+ mesons are discussed as well as the leptonic decay $D^+ \to \mu^+\nu_\mu$ and determination of the D meson decay constant.

1 Introduction

The CLEO-c experiment at the Cornell Electron Positron Storage Ring has recorded 281 pb^{-1} at the $\psi(3770)$. This sample provides a very clean environment for studying decays of D mesons. The $\psi(3770)$ produced in the e^+e^- annihilation decays to pairs of D mesons, either D^+D^- or $D^0\bar{D}^0$. In particular, the produced D mesons can not be accompanied by any additional pions.

The analyses presented here all have in common that they use a tagging technique. This technique was used by the MARK III collaboration [1]. In these analyses one of the D mesons is fully reconstructed in a hadronic final state. From energy and momentum conservation we can predict the four-momentum of the other D meson in the event.

We report here on measurements of the absolute hadronic branching fractions of D^0 and D^+ mesons, measurements of semileptonic branching fractions and the measurement of the branching fraction for the leptonic decay $D^+ \to \mu^+\nu_\mu$ and the determination of the D meson decay constant f_D.

2 Absolute D hadronic branching fractions

Determination of the absolute hadronic branching fractions for D mesons is important as they provide the normalization for practically all B decays, and as such impact for example the determination of $|V_{cb}|$ using exclusive $B \to D^*\ell\nu$. The branching fractions for D^0 decays have been measured to about 3% prior to CLEO-c while D^+ meson branching fractions were only known to about 6%. The results presented here on 56 pb^{-1} represent significant improvements to the D^+ branching fractions [2].

This analysis makes use of a 'double tag' technique in which we determine the number of single tags, separately for D and $\bar{D}$ decays, $N_i = \epsilon_i \mathcal{B}_i N_{D\bar{D}}$ and $\bar{N}_j = \bar{\epsilon}_j \mathcal{B}_j N_{D\bar{D}}$ where ϵ_i and $\mathcal{B}_i$ are the efficiencies and branching fractions for mode i. Similarly we reconstruct double tags where both D mesons are found. The number of double tags found is given by $N_{ij} = \epsilon_{ij}\mathcal{B}_i\mathcal{B}_j N_{D\bar{D}}$ where i and j label the D and $\bar{D}$ mode used to reconstruct the event and ϵ_{ij} is the efficency for

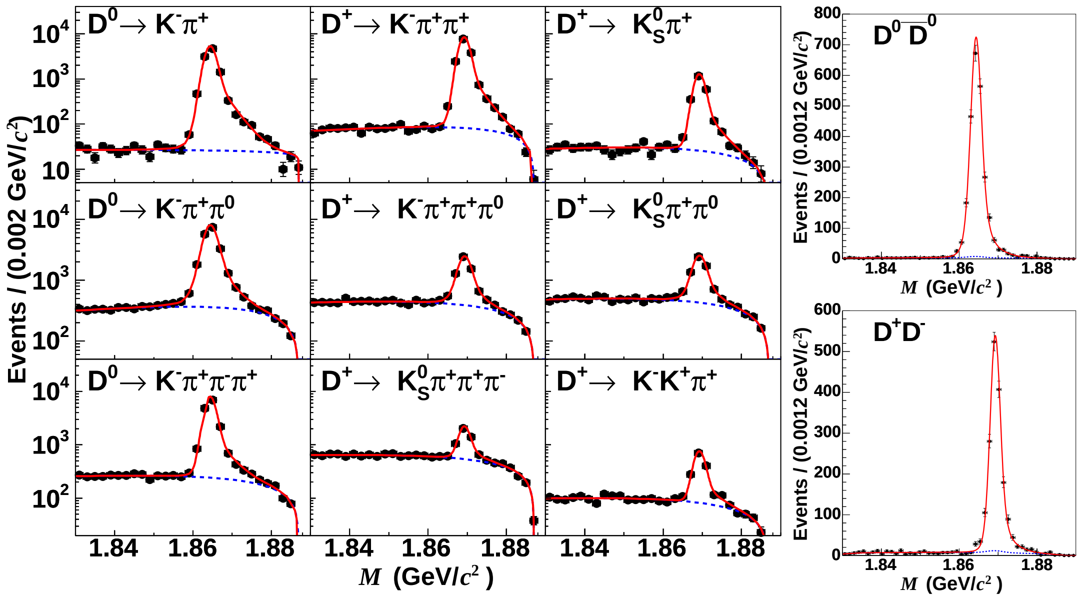

Figure 1: Yields for single tags, left, and double tag yields combined an all neutral and charged modes respectively in the right two plots.

Table 1: Fitted branching fractions and $D\bar{D}$ pair yields. Uncertainties are statistical and systematic, respectively.

Parameter	Fitted Value	PDG
$N_{D^0\bar{D}^0}$	$(2.01 \pm 0.04 \pm 0.02) \times 10^5$	—
$\mathcal{B}(D^0 \to K^-\pi^+)$	$(3.91 \pm 0.08 \pm 0.09)\%$	$3.81 \pm 0.09\%$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^0)$	$(14.9 \pm 0.3 \pm 0.5)\%$	$13.2 \pm 1.0\%$
$\mathcal{B}(D^0 \to K^-\pi^+\pi^+\pi^-)$	$(8.3 \pm 0.2 \pm 0.3)\%$	$7.48 \pm 0.30\%$
$N_{D^+D^-}$	$(1.56 \pm 0.04 \pm 0.01) \times 10^5$	—
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+)$	$(9.5 \pm 0.2 \pm 0.3)\%$	$9.2 \pm 0.6\%$
$\mathcal{B}(D^+ \to K^-\pi^+\pi^+\pi^0)$	$(6.0 \pm 0.2 \pm 0.2)\%$	$6.5 \pm 1.1\%$
$\mathcal{B}(D^+ \to K^0_S\pi^+)$	$(1.55 \pm 0.05 \pm 0.06)\%$	$1.42 \pm 0.09\%$
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^0)$	$(7.2 \pm 0.2 \pm 0.4)\%$	$5.4 \pm 1.5\%$
$\mathcal{B}(D^+ \to K^0_S\pi^+\pi^+\pi^-)$	$(3.2 \pm 0.1 \pm 0.2)\%$	$3.6 \pm 0.5\%$
$\mathcal{B}(D^+ \to K^+K^-\pi^+)$	$(0.97 \pm 0.04 \pm 0.04)\%$	$0.89 \pm 0.08\%$

reconstructing the final state. Combining the two equations above we can solve for $N_{D\bar{D}}$ as

$$N_{D\bar{D}} = \frac{N_i \bar{N}_j}{N_{ij}} \frac{\epsilon_{ij}}{\epsilon_i \bar{\epsilon}_j}.$$

In this analysis we make use of three D^0 decays and six D^+ modes as shown in Fig. 1. We have a total of $2,484 \pm 51$ neutral double tags and $1,650 \pm 42$ charged double tags. The scale of the statistical error on the branching fractions are set by the number of double tags, $\approx 2.0\%$ and $\approx 2.5\%$ for the neutral and charged modes respectively. The branching fractions obtained are summarized in Table 1.

3 Semileptonic D decays

Semileptonic branching fractions have been studied for several Cabibbo favored and suppressed modes in a sample of 56 pb^{-1}. In this analysis we reconstruct one D meson and look at the recoil D to identify the signal[3,4]. The signal is identified by requiring that one electron is found and the hadronic final state is reconstructed. This means that all particles except the neutrino

Table 2: Branching fractions for semileptonic D^0 and D^+ meson decays. Uncertainties are statistical and systematic, respectively.

Mode	$\mathcal{B}(\%)$ CLEOC-c	$\mathcal{B}(\%)$ PDG
$D^0 \to \pi^- e^+ \nu_e$	$0.26 \pm 0.03 \pm 0.01$	0.36 ± 0.06
$D^0 \to K^- e^+ \nu_e$	$3.44 \pm 0.10 \pm 0.10$	3.58 ± 0.18
$D^0 \to K^{*-}(K^-\pi^0) e^+ \nu_e$	$2.11 \pm 0.23 \pm 0.10$	2.15 ± 0.35
$D^0 \to K^{*-}(\bar{K}^0\pi^-) e^+ \nu_e$	$2.19 \pm 0.20 \pm 0.11$	2.15 ± 0.35
$D^0 \to \rho^- e^+ \nu_e$	$0.19 \pm 0.03 \pm 0.04$	—
$D^+ \to \pi^0 e^+ \nu_e$	$0.44 \pm 0.06 \pm 0.03$	0.31 ± 0.15
$D^+ \to \bar{K}^0 e^+ \nu_e$	$8.71 \pm 0.38 \pm 0.37$	6.7 ± 0.9
$D^+ \to \bar{K}^{*0} e^+ \nu_e$	$5.56 \pm 0.27 \pm 0.23$	5.5 ± 0.7
$D^0 \to \rho^0 e^+ \nu_e$	$0.21 \pm 0.04 \pm 0.01$	0.25 ± 0.10
$D^0 \to \omega^0 e^+ \nu_e$	$0.16^{+0.07}_{-0.06} \pm 0.01$	—

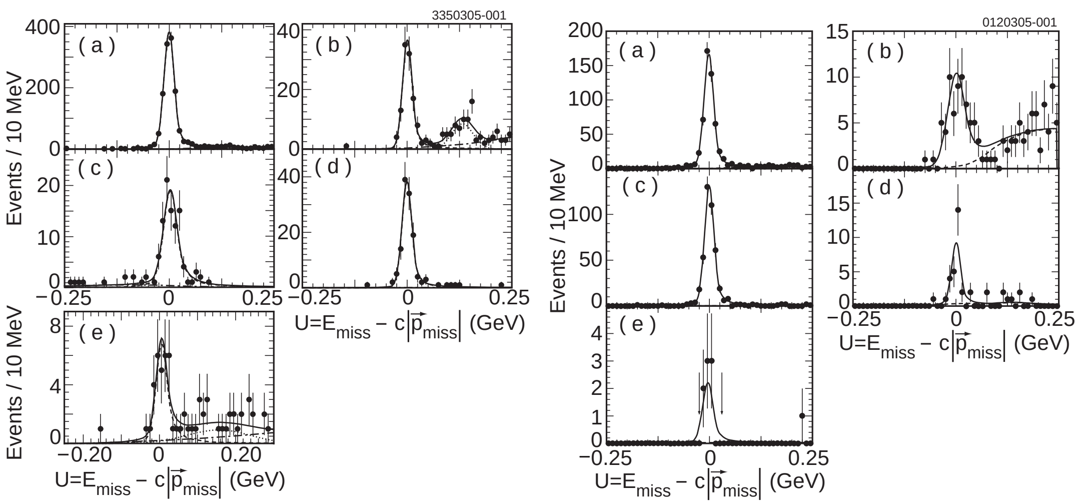

Figure 2: Left: Yields of D^0 semileptonic decays to a) $K^- e^+ \nu_e$, b) $\pi^- e^+ \nu_e$, c) $K^{*-}(K^-\pi^0) e^+ \nu_e$, d) $K^{*-}(\bar{K}^0\pi^-) e^+ \nu_e$, and e) $\rho^- e^+ \nu_e$. Right: Yields of D^+ semileptonic decays to a) $\bar{K}^0 e^+ \nu_e$, b) $\bar{K}^{*0} e^+ \nu_e$, c) $\pi^0 e^+ \nu_e$, d) $\rho^0 e^+ \nu_e$, and e) $\omega e^+ \nu_e$.

is reconstructed. Using four-momentum conservation we can infer the energy and momentum of the neutrino. To extract the signal we form a quantity known as $U = E - P$ which is the energy minus the momentum for the neutrino. For signal events this quantity should peak at zero.

Figure 2 shows the semileptonic yields for D^0 and D^+ decays. The extracted branching fractions are summarized in Table 2.

4 Leptonic D^+ decays and f_D

The decay $D^+ \to \mu^+ \nu_\mu$ provides a direct measurement of the D meson decay constant, f_D. The partial width for $D^+ \to \ell^+ \nu_\ell$ is given by

$$\Gamma(D^+ \to \mu^+ \nu_\mu) = \frac{G_F^2}{8\pi} f_D^2 m_D m_\ell^2 \left[1 - \frac{m_\ell^2}{m_D^2}\right]^2 |V_{cd}|^2$$

where all factors are known except for the decay constant. A measurement of the branching fraction combined with the well known D^+ lifetime allows us to determine the decay constant. Precise measurements of the decay constant in D and D_s decays allow for precise tests of Lattice QCD.

This analysis reconstructs charged D mesons in six modes, a total $158,354 \pm 496$ tags were reconstructed in the 281 pb^{-1} sample. We look for one, and only one additional track from the interaction point in the event. We require this track to be consistent with being a muon by its energy deposit in the electromagnetic calorimeter (EMC), we require less than 350 MeV to be deposited. In addition, to veto events from $D^+ \to \pi^+\pi^0$, we require that there were no extra, unmatched, showers in the EMC with an energy of over 250 MeV.

For events that satisfy these requirements we calculate the missing mass square, M^2_{miss}. This is the mass that the tag D and muon candidate is recoiling against. For signal events this will peak at $M^2_{\mathrm{miss}} = m^2_\nu = 0$. Figure 3 shows the observed missing mass square distribution. The signal region contains 50 events. An evaluations of the backgrounds gives an estimate of $2.81 \pm 0.30 \pm 0.27$ background events in the signal region. Combining the signal yield of $47.2 \pm 7.1^{+0.3}_{-0.8}$ events with the number of tags and the signal detection efficiency we find

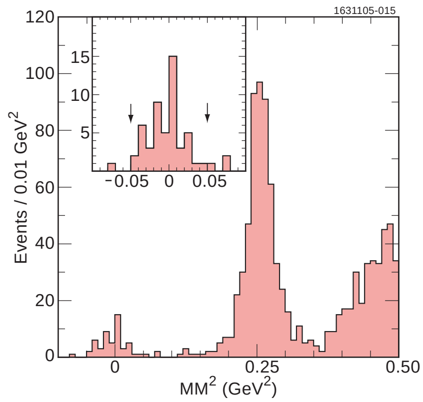

Figure 3: Missing mass squared distribution for the $D^+ \to \mu^+\nu_\mu$ candidates.

$$\mathcal{B}(D^+ \to \mu^+\nu_\mu) = (4.40 \pm 0.66^{+0.09}_{-0.12}) \times 10^{-4}$$

and the decay constant $f_D = (222.6 \pm 16.7^{+2.8}_{-3.4})$ MeV. This measurement is in good agreement with theoretical predictions. In particular, a recent unquenched lattice calculation by the Fermilab-MILC-HPQCD collaboration [6] gives $f_D = (201 \pm 3 \pm 17)$ MeV.

5 Summary

The CLEO-c experiment has recorded 281 pb^{-1} of e^+e^- annihilation data at the $\psi(3770)$. Here results for hadronic branching fractions and semileptonic decays were presented on 56 pb^{-1} and the leptonic decay was based on the full 281 pb^{-1} sample. CLEO-c will run until March 31, 2008 and we plan to record a total of about 750 pb^{-1} at the $\psi(3770)$. We have also recorded a sample of about 200 pb^{-1} at $E_{\mathrm{CM}} \approx 4170$ MeV. The goal is to recored a sample of 750 pb^{-1} at this energy for D_s studies.

Acknowledgments

This work was supported by the National Science Foundation grant PHY-0202078 and by the Alfred P. Sloan fundation.

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